US009346371B2

(12) **United States Patent**
King et al.

(10) **Patent No.: US 9,346,371 B2**
(45) **Date of Patent: *May 24, 2016**

(54) **TRANSPORT SYSTEM POWERED BY SHORT BLOCK LINEAR SYNCHRONOUS MOTORS**

(71) Applicant: **MAGNEMOTION, INC.**, Devens, MA (US)

(72) Inventors: **Nathanael N. King**, Somerville, MA (US); **Brian M. Perreault**, Stow, MA (US); **Tracy M. Clark**, Bedford, MA (US); **Richard D. Thornton**, Concord, MA (US); **Jason Young**, Devens, MA (US); **Michael W. Bottasso**, Maynard, MA (US)

(73) Assignee: **MAGNEMOTION, INC.**, Devens, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/143,802**

(22) Filed: **Dec. 30, 2013**

(65) **Prior Publication Data**

US 2014/0182478 A1 Jul. 3, 2014

Related U.S. Application Data

(63) Continuation of application No. 12/359,022, filed on Jan. 23, 2009, now Pat. No. 8,616,134.

(51) **Int. Cl.**
B60L 13/06 (2006.01)
B60L 1/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***B60L 13/03*** (2013.01); ***B60L 13/003*** (2013.01); ***B60L 13/10*** (2013.01); *B60L 2200/26* (2013.01)

(58) **Field of Classification Search**
CPC B60L 11/00; B60L 11/002; B60L 13/00; B60L 13/006; B60L 13/04; B60L 13/16; B60L 15/00; B60L 5/002; B60M 1/00; B60M 1/02; B60M 1/16; B60M 1/30
USPC .... 104/281–284; 191/2, 6, 22 R, 33 R
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

527,857 A 10/1894 Hutin et al.
2,193,076 A 3/1940 Preble
(Continued)

FOREIGN PATENT DOCUMENTS

CA 2 422 341 A1 9/2004
CH 427872 A 1/1967
(Continued)

OTHER PUBLICATIONS

Japanese Office Action for Application No. 2011-548142 issued Jan. 6, 2015 (7 Pages).

(Continued)

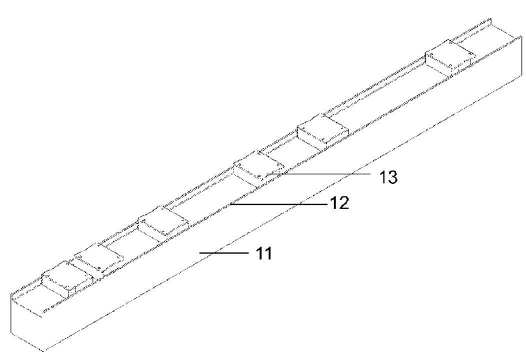
Primary Examiner — R. J. McCarry, Jr.
(74) *Attorney, Agent, or Firm* — Nutter McClennen & Fish LLP; David J. Powsner; Derek P. Roller

(57) **ABSTRACT**

Aspects of the invention provide a transport system powered by short block Linear Synchronous Motors (LSMs). The use of short blocks allows vehicles to move under precise control even when they are in close proximity to each other. The design allows the vehicles to be propelled and guided while negotiating sharp turns and negotiating merge and diverge switches. A coreless LSM can be used to create propulsive force without attractive force so as to allow a relatively high drag vehicle suspension, such as a vehicle sliding on a smooth surface.

30 Claims, 14 Drawing Sheets

Straight guideway showing vehicles moving in close proximity.



(51) **Int. Cl.**
B60L 13/03 (2006.01)
B60L 13/00 (2006.01)
B60L 13/10 (2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,684,753	A	7/1954	Kolbe et al.
2,772,640	A	12/1956	Nystrom
2,873,843	A	2/1959	Wilson
3,029,893	A	4/1962	Mountjoy
3,158,765	A	11/1964	Polgreen
3,179,241	A	4/1965	Kain
3,308,312	A	3/1967	Ehrenberg
3,376,578	A	4/1968	Sawyer
3,426,887	A	2/1969	Ward et al.
3,440,600	A	4/1969	Frech et al.
3,513,338	A	5/1970	Poloujadoff
3,532,934	A	10/1970	Ballman
3,547,041	A	12/1970	Izhelya et al.
3,607,659	A	9/1971	Bloomer
3,609,676	A	9/1971	Jauquet et al.
3,617,890	A	11/1971	Kurauchi et al.
3,628,462	A	12/1971	Holt
3,636,508	A	1/1972	Ogilvy et al.
3,638,093	A	1/1972	Ross
3,656,015	A	4/1972	Gillum
3,661,091	A	5/1972	Noble
3,663,131	A	5/1972	Hegewaldt et al.
3,669,247	A	6/1972	Pulver
3,670,659	A	6/1972	Schurch
3,675,585	A	7/1972	Wiart et al.
3,679,874	A	7/1972	Fickenscher
3,696,753	A	10/1972	Ross et al.
3,706,922	A	12/1972	Inagaki
3,708,059	A	1/1973	Ackermann
3,719,869	A	3/1973	Coho
3,721,874	A	3/1973	Pelenc et al.
3,749,025	A	7/1973	Giraud
3,762,334	A	10/1973	Larson
3,763,788	A	10/1973	Pougue
3,768,417	A	10/1973	Thornton et al.
3,772,640	A	11/1973	Auer, Jr. et al.
3,782,291	A	1/1974	Maison
3,786,411	A	1/1974	Kurauchi et al.
3,788,447	A	1/1974	Stephanoff
3,788,455	A	1/1974	Dieckmann, Jr.
3,792,665	A	2/1974	Nelson
3,803,466	A	4/1974	Starkey
3,808,977	A	5/1974	Smoot et al.
3,834,318	A	9/1974	Fellows et al.
3,835,785	A	9/1974	Kirschner et al.
3,842,751	A	10/1974	Thornton et al.
3,845,720	A	11/1974	Bohn et al.
3,847,088	A	11/1974	Karch
3,850,108	A	11/1974	Winkle
3,850,109	A	11/1974	Thornton
3,858,521	A	1/1975	Atherton et al.
3,860,300	A	1/1975	Lyman
3,860,843	A	1/1975	Kawasaki et al.
3,871,301	A	3/1975	Kolm et al.
3,874,299	A	4/1975	Silva et al.
3,874,301	A	4/1975	Alimanestianu
3,882,789	A	5/1975	Simon et al.
3,890,421	A	6/1975	Habozit
3,899,979	A	8/1975	Godsey, Jr.
3,904,942	A	9/1975	Holtz
3,906,436	A	9/1975	Kurauchi et al.
3,908,555	A	9/1975	Henderson et al.
3,912,991	A	10/1975	Moyse et al.
3,912,992	A	10/1975	Lamb et al.
3,927,735	A	12/1975	Miericke et al.
3,937,148	A	2/1976	Simpson
3,938,018	A	2/1976	Dahl
3,974,778	A	8/1976	Black et al.
3,979,091	A	9/1976	Gagnon et al.
3,994,236	A	11/1976	Dull et al.
4,013,014	A	3/1977	Holtz
4,015,540	A	4/1977	Roxberry
4,023,753	A	5/1977	Dobler et al.
4,044,881	A	8/1977	Chai et al.
4,061,089	A	12/1977	Sawyer
4,065,706	A	12/1977	Gosling et al.
4,068,152	A	1/1978	Nakamura et al.
4,081,723	A	3/1978	Vetter et al.
4,088,379	A	5/1978	Perper
4,109,584	A	8/1978	Mihirogi
4,123,175	A	10/1978	Carlson et al.
4,132,175	A	1/1979	Miller et al.
4,140,063	A	2/1979	Nakamura
4,160,181	A	7/1979	Lichtenberg
4,292,465	A	9/1981	Wilson et al.
4,311,853	A	1/1982	Cree
4,311,953	A	1/1982	Fukuda et al.
4,318,038	A	3/1982	Munehiro
4,348,618	A	9/1982	Nakamura et al.
4,352,960	A	10/1982	Dormer et al.
4,361,095	A	11/1982	Gibson
4,361,202	A	11/1982	Minovitch
4,395,746	A	7/1983	Tanaka et al.
4,401,181	A	8/1983	Schwarz
4,415,959	A	11/1983	Vinciarelli
4,424,463	A	1/1984	Musil
4,427,905	A	1/1984	Sutton
4,441,604	A	4/1984	Schlig et al.
4,444,550	A	4/1984	Loubier
4,454,457	A	6/1984	Nakamura et al.
4,472,706	A	9/1984	Hodge et al.
4,513,235	A	4/1985	Acklam et al.
4,522,128	A	6/1985	Anderson
4,538,214	A	8/1985	Fisher et al.
4,542,311	A	9/1985	Newman et al.
4,571,236	A	2/1986	Adams
4,583,028	A	4/1986	Angersbach et al.
4,592,034	A	5/1986	Sachse et al.
4,595,870	A	6/1986	Chitayat
4,595,877	A	6/1986	Dulk et al.
4,603,640	A	8/1986	Miller et al.
4,633,108	A	12/1986	von der Heide et al.
4,635,560	A	1/1987	Ballantyne
4,638,192	A	1/1987	von der Heide et al.
4,639,648	A	1/1987	Sakamoto
4,646,651	A	3/1987	Yamamura et al.
4,665,829	A	5/1987	Anderson
4,665,830	A	5/1987	Anderson et al.
4,666,829	A	5/1987	Glenner et al.
4,671,185	A	6/1987	Anderson et al.
4,675,582	A	6/1987	Hommes et al.
4,678,971	A	7/1987	Kanazawa et al.
4,689,530	A	8/1987	Nakamura et al.
4,692,654	A	9/1987	Umemura et al.
4,698,895	A	10/1987	Miller et al.
4,698,996	A	10/1987	Kreft et al.
4,704,568	A	11/1987	Beck et al.
4,704,792	A	11/1987	Itagaki et al.
4,711,182	A	12/1987	Alexandrov et al.
4,714,400	A	12/1987	Barnett et al.
4,720,008	A	1/1988	Ufland
4,721,045	A	1/1988	Okawa et al.
4,721,892	A	1/1988	Nakamura et al.
4,726,299	A	2/1988	Anderson
4,732,087	A	3/1988	Morishita et al.
4,736,747	A	4/1988	Drake
4,746,849	A	5/1988	Rosshirt
4,760,294	A	7/1988	Hansen
4,769,580	A	9/1988	Heidelberg et al.
4,776,464	A	10/1988	Miller et al.
4,782,342	A	11/1988	Walton
4,786,891	A	11/1988	Ueda et al.
4,789,815	A	12/1988	Kobayashi et al.
4,794,865	A	1/1989	Lindberg
4,800,328	A	1/1989	Bolger et al.
4,800,818	A	1/1989	Kawaguchi et al.
4,808,892	A	2/1989	Dreibelbis
4,811,667	A	3/1989	Morishita et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,825,111 A 4/1989 Hommes et al.
4,826,344 A 5/1989 Rakiec
4,829,445 A 5/1989 Burney
4,836,344 A 6/1989 Bolger
4,841,869 A 6/1989 Takeuchi et al.
4,847,526 A 7/1989 Takehara et al.
4,849,664 A 7/1989 Miyazaki et al.
4,853,602 A 8/1989 Hommes et al.
4,873,677 A 10/1989 Sakamoto et al.
4,890,023 A 12/1989 Hinds et al.
4,892,980 A 1/1990 Riley
4,893,071 A 1/1990 Miller
4,906,909 A 3/1990 Gremillion et al.
4,912,746 A 3/1990 Oishi
4,914,539 A 4/1990 Turner et al.
4,920,318 A 4/1990 Misic et al.
4,953,470 A 9/1990 Yamaguchi
4,955,303 A 9/1990 Ikeda
4,972,779 A 11/1990 Morishita et al.
4,982,556 A 1/1991 Tisma
5,001,479 A 3/1991 Becker et al.
5,003,260 A 3/1991 Auchterlonie
5,014,625 A 5/1991 Murai et al.
5,021,778 A 6/1991 Walton
5,023,495 A 6/1991 Ohsaka et al.
5,032,746 A 7/1991 Ueda et al.
5,032,747 A 7/1991 Sakamoto et al.
5,047,676 A 9/1991 Ichikawa
5,051,225 A 9/1991 Hommes et al.
5,053,654 A 10/1991 Augsburger et al.
5,055,775 A 10/1991 Scherz et al.
5,072,144 A 12/1991 Saito et al.
5,072,493 A 12/1991 Hommes et al.
5,091,665 A 2/1992 Kelly
5,092,450 A 3/1992 Schommartz et al.
5,093,590 A 3/1992 Murai et al.
5,094,172 A 3/1992 Kummer
5,108,052 A 4/1992 Malewicki et al.
5,121,830 A 6/1992 Sakamoto et al.
5,125,347 A 6/1992 Takahashi et al.
5,126,606 A 6/1992 Hofmann et al.
5,126,648 A 6/1992 Jacobs
5,136,217 A 8/1992 Hoffmann et al.
5,152,227 A 10/1992 Kato et al.
5,156,092 A 10/1992 Hirtz
5,161,758 A 11/1992 Shuto et al.
5,165,527 A 11/1992 Garbagnati
5,175,976 A 1/1993 Petry et al.
5,178,037 A 1/1993 Mihirogi et al.
5,180,041 A 1/1993 Shuto et al.
5,185,984 A 2/1993 Tisma
5,193,767 A 3/1993 Mihirogi et al.
5,197,391 A 3/1993 Shimada et al.
5,199,674 A 4/1993 Mihirogi et al.
5,205,395 A 4/1993 Bruno et al.
5,214,323 A 5/1993 Ueda et al.
5,214,981 A 6/1993 Weinberger et al.
5,225,024 A 7/1993 Hanley et al.
5,225,725 A 7/1993 Shiraki et al.
5,225,726 A 7/1993 Tozoni
5,229,669 A 7/1993 Takei et al.
5,237,252 A 8/1993 Tanaka et al.
5,242,136 A 9/1993 Cribbens et al.
5,247,890 A 9/1993 Mihirogi et al.
5,251,563 A 10/1993 Staehs et al.
5,263,670 A 11/1993 Colbaugh et al.
5,267,514 A 12/1993 Staehs et al.
5,277,124 A 1/1994 DiFonso et al.
5,277,125 A 1/1994 DiFonso et al.
5,277,285 A 1/1994 Musachio
5,282,424 A 2/1994 O'Neill
5,289,088 A 2/1994 Andoh et al.
5,293,308 A 3/1994 Boys et al.
5,317,245 A 5/1994 Moritz et al.
5,325,974 A 7/1994 Staehs
5,347,456 A 9/1994 Zhang et al.
5,361,707 A 11/1994 Fujie et al.
5,362,222 A 11/1994 Faig et al.
5,368,425 A 11/1994 Mills et al.
5,370,059 A 12/1994 Raschbichler et al.
5,400,668 A 3/1995 Hattori et al.
5,409,095 A 4/1995 Hoshi et al.
5,409,356 A 4/1995 Massie
5,412,317 A 5/1995 Kyoizumi
5,433,155 A 7/1995 O'Neill et al.
5,435,429 A 7/1995 Van Den Goor et al.
5,444,341 A 8/1995 Kneifel, II et al.
5,450,305 A 9/1995 Boys et al.
5,452,201 A 9/1995 Pieronek et al.
5,452,663 A 9/1995 Berdut et al.
5,458,047 A 10/1995 McCormick
5,467,718 A 11/1995 Shibata et al.
5,497,038 A 3/1996 Sink
5,502,383 A 3/1996 Funami et al.
5,517,924 A 5/1996 He et al.
5,519,266 A 5/1996 Chitayat
5,521,444 A 5/1996 Foreman
5,521,451 A 5/1996 Oudet et al.
5,523,637 A 6/1996 Miller
5,528,113 A 6/1996 Boys et al.
5,542,356 A 8/1996 Richert et al.
5,551,350 A 9/1996 Yamada et al.
5,552,689 A 9/1996 Matoba
5,560,476 A 10/1996 Lee
5,565,718 A 10/1996 Takei
5,573,090 A 11/1996 Ross
5,590,278 A 12/1996 Barthel et al.
5,590,281 A 12/1996 Stevens
5,590,604 A 1/1997 Lund
5,590,995 A 1/1997 Berkers et al.
5,592,158 A 1/1997 Riffaud et al.
5,595,121 A 1/1997 Elliott et al.
5,605,100 A 2/1997 Morris et al.
5,606,256 A 2/1997 Takei
5,619,078 A 4/1997 Boys et al.
5,628,252 A 5/1997 Kuznetsov
5,642,013 A 6/1997 Wavre
5,644,176 A 7/1997 Katagiri et al.
5,653,173 A 8/1997 Fischer
5,668,421 A 9/1997 Gladish et al.
5,669,310 A 9/1997 Powell et al.
5,669,470 A 9/1997 Ross
5,684,344 A 11/1997 Takei
5,689,164 A 11/1997 Hoft et al.
5,689,994 A 11/1997 Nagai et al.
5,701,042 A 12/1997 Takei et al.
5,703,417 A 12/1997 Kelly
5,708,427 A 1/1998 Bush
5,709,291 A 1/1998 Nishino et al.
5,712,514 A 1/1998 Fischperer et al.
5,715,657 A 2/1998 Mondani et al.
5,720,454 A 2/1998 Bachetti et al.
5,722,326 A 3/1998 Post
5,723,917 A 3/1998 Chitayat
5,729,251 A 3/1998 Nakashima
5,757,091 A 5/1998 Sogabe et al.
5,757,100 A 5/1998 Burgbacher et al.
5,757,288 A 5/1998 Dixon et al.
5,763,966 A 6/1998 Hinds
5,768,856 A 6/1998 Odenthal
5,770,936 A 6/1998 Hirai et al.
5,773,941 A 6/1998 Moritz et al.
5,789,892 A 8/1998 Takei
5,793,128 A 8/1998 Nanba et al.
5,810,153 A 9/1998 Zimmerman et al.
5,821,638 A 10/1998 Boys et al.
5,828,142 A 10/1998 Simpson
5,831,352 A 11/1998 Takei
5,839,554 A 11/1998 Clark et al.
5,839,567 A 11/1998 Kyotani et al.
5,845,581 A 12/1998 Svensson
5,896,031 A 4/1999 King
5,898,579 A 4/1999 Boys et al.
5,900,728 A 5/1999 Moser et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,904,101	A	5/1999	Kuznetsov
5,906,647	A	5/1999	Zyburt et al.
5,907,200	A	5/1999	Chitayat
5,910,691	A	6/1999	Wavre et al.
5,920,164	A	7/1999	Moritz et al.
5,925,943	A	7/1999	Chitayat
5,925,956	A	7/1999	Ohzeki
5,927,657	A	7/1999	Takasan et al.
5,929,541	A	7/1999	Naito et al.
5,936,319	A	8/1999	Chitayat
5,938,577	A	8/1999	Lindem
5,939,845	A	8/1999	Hommes
5,942,817	A	8/1999	Chitayat
5,947,361	A	9/1999	Berger et al.
5,950,543	A	9/1999	Oster
5,952,742	A	9/1999	Stoiber et al.
5,952,743	A	9/1999	Sidey et al.
5,962,937	A	10/1999	Wavre
5,965,963	A	10/1999	Chitayat
5,977,664	A	11/1999	Chitayat
5,990,592	A	11/1999	Miura et al.
5,994,798	A	11/1999	Chitayat
5,998,989	A	12/1999	Lohberg
6,005,310	A	12/1999	Mosciatti et al.
6,005,511	A	12/1999	Young et al.
6,008,552	A	12/1999	Yagoto et al.
6,011,508	A	1/2000	Perreault et al.
6,016,044	A	1/2000	Holdaway
6,025,659	A	2/2000	Nashiki
6,032,110	A	2/2000	Ishihara et al.
6,034,499	A	3/2000	Tranovich
6,044,770	A	4/2000	Davey et al.
6,064,301	A	5/2000	Takahashi et al.
6,075,297	A	6/2000	Izawa et al.
6,078,114	A	6/2000	Bessette et al.
6,081,058	A	6/2000	Suzuki et al.
6,085,496	A	7/2000	Fontanazzi et al.
6,087,742	A	7/2000	Maestre
6,089,512	A	7/2000	Ansorge et al.
6,100,663	A	8/2000	Boys et al.
6,100,821	A	8/2000	Tanji et al.
6,101,952	A	8/2000	Thornton et al.
6,104,117	A	8/2000	Nakamura et al.
6,105,338	A	8/2000	Kalany et al.
6,114,825	A	9/2000	Katz
6,118,249	A	9/2000	Brockmann et al.
6,137,424	A	10/2000	Cohen et al.
6,147,421	A	11/2000	Takita et al.
6,175,169	B1	1/2001	Hollis, Jr. et al.
6,191,507	B1	2/2001	Peltier et al.
6,193,199	B1	2/2001	Karam, II
6,202,392	B1	3/2001	Greenwell et al.
6,220,424	B1	4/2001	Fluck
6,225,919	B1	5/2001	Lumbis et al.
6,236,124	B1	5/2001	Sekiyama et al.
6,242,822	B1	6/2001	Strothmann et al.
6,257,604	B1	7/2001	Laurent et al.
6,274,952	B1	8/2001	Chitayat
6,285,988	B1	9/2001	Nogami
6,286,290	B1	9/2001	Fluck
6,286,434	B1	9/2001	Fischperer et al.
6,297,610	B1	10/2001	Bauer et al.
6,307,766	B1	10/2001	Ross et al.
6,315,108	B1	11/2001	Bootsman et al.
6,317,338	B1	11/2001	Boys et al.
6,326,708	B1	12/2001	Tsuboi et al.
6,326,713	B1	12/2001	Judson
6,376,957	B1	4/2002	Haydock et al.
6,397,755	B1	6/2002	Kamler
6,397,990	B1	6/2002	Brien et al.
6,400,278	B1	6/2002	Weyerstall et al.
6,414,742	B1	7/2002	Korenaga et al.
6,417,584	B1	7/2002	Chitayat
6,417,914	B1	7/2002	Li
6,418,857	B1	7/2002	Okano et al.

6,421,984	B1	7/2002	Murgatroyd et al.
6,445,093	B1	9/2002	Binnard
6,455,957	B1	9/2002	Chitayat
6,483,202	B1	11/2002	Boys
6,495,941	B1	12/2002	Nishimura et al.
6,499,701	B1	12/2002	Thornton et al.
6,534,894	B1	3/2003	Flowerday
6,578,495	B1	6/2003	Yitts et al.
6,580,185	B2	6/2003	Kang et al.
6,619,212	B1	9/2003	Stephan et al.
6,621,183	B1	9/2003	Boys
6,625,517	B1	9/2003	Bogdanov et al.
6,637,343	B2	10/2003	Stephan et al.
6,644,176	B2	11/2003	Prip
6,646,721	B2	11/2003	Compter et al.
6,650,079	B2	11/2003	Binnard
6,651,566	B2	11/2003	Stephan et al.
6,684,794	B2	2/2004	Fiske et al.
6,686,823	B2	2/2004	Arntz et al.
6,703,806	B2	3/2004	Joong et al.
6,713,902	B2	3/2004	Chitayat
6,715,598	B2	4/2004	Affaticati et al.
6,718,197	B1	4/2004	Carlson et al.
6,781,524	B1	8/2004	Clark et al.
6,784,572	B1	8/2004	Backman et al.
6,788,385	B2	9/2004	Tanaka et al.
6,803,681	B2	10/2004	Faizullabhoy et al.
6,803,744	B1	10/2004	Sabo
6,834,595	B1	12/2004	Henderson
6,857,374	B2	2/2005	Novacek
6,875,107	B1	4/2005	Luciano, Jr.
6,876,105	B1	4/2005	Faizullabhoy et al.
6,876,107	B2	4/2005	Jacobs
6,876,896	B1	4/2005	Ortiz et al.
6,899,037	B1	5/2005	Cowan, Jr.
6,910,568	B1	6/2005	Ydoate et al.
6,911,747	B2	6/2005	Tsuboi et al.
6,917,136	B2	7/2005	Thornton et al.
6,930,413	B2	8/2005	Marzano
6,963,148	B1	11/2005	Faizullabhoy et al.
6,975,081	B1	12/2005	Faizullabhoy et al.
6,983,701	B2	1/2006	Thornton et al.
7,009,683	B2	3/2006	Sato et al.
7,019,818	B2	3/2006	Opower et al.
7,026,732	B1	4/2006	Backman et al.
7,134,258	B2	11/2006	Kalany et al.
7,170,241	B1	1/2007	Faizullabhoy et al.
RE39,747	E	7/2007	Peltier et al.
7,243,752	B2	7/2007	Green et al.
7,262,523	B1	8/2007	Faizullabhoy et al.
7,432,622	B2	10/2008	Griepentrog et al.
7,448,327	B2	11/2008	Thornton et al.
7,456,529	B2	11/2008	Faizullabhoy et al.
7,456,593	B1	11/2008	Floresta et al.
7,458,454	B2	12/2008	Mendenhall
7,511,250	B2	3/2009	Lindig
7,525,283	B2	4/2009	Cheng et al.
7,538,469	B2	5/2009	Thornton et al.
7,554,316	B2	6/2009	Stevens et al.
7,602,142	B2	10/2009	Weber et al.
7,605,496	B2	10/2009	Stevens et al.
7,633,235	B2	12/2009	Boys
7,714,537	B2	5/2010	Cheng et al.
7,781,993	B1	8/2010	Faizullabhoy et al.
7,825,537	B2	11/2010	Freer
7,859,139	B2	12/2010	Jacobs
7,863,861	B2	1/2011	Cheng et al.
7,868,587	B2	1/2011	Stevens et al.
7,913,606	B2	3/2011	Schneider et al.
7,926,644	B2	4/2011	Mendenhall
7,932,798	B2	4/2011	Tolle et al.
7,952,322	B2	5/2011	Partovi et al.
7,952,324	B2	5/2011	Cheng et al.
8,074,578	B2	12/2011	Thornton
8,076,803	B2	12/2011	Jacobs
8,113,310	B2	2/2012	Gurol et al.
8,502,422	B2	8/2013	Lykkegaard
8,616,134	B2 *	12/2013	King et al. 104/284
8,863,669	B2	10/2014	Young et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,967,051	B2	3/2015	King et al.
9,032,880	B2	5/2015	King et al.
2001/0045526	A1	11/2001	Itoh et al.
2002/0024979	A1	2/2002	Vilhelmsson et al.
2002/0047315	A1	4/2002	Chitayat
2002/0089237	A1	7/2002	Hazelton
2002/0093252	A1	7/2002	Kang et al.
2002/0149272	A1	10/2002	Chitayat
2002/0180279	A1	12/2002	Faizullabhoy et al.
2002/0185919	A1	12/2002	Botos et al.
2003/0025403	A1	2/2003	Hsiao
2003/0107289	A1	6/2003	Thornton et al.
2003/0136086	A1	7/2003	Kalany et al.
2003/0217668	A1	11/2003	Fiske et al.
2003/0230941	A1	12/2003	Jacobs
2004/0119358	A1	6/2004	Thornton et al.
2005/0172850	A1	8/2005	Sakita
2005/0225188	A1	10/2005	Griepentrog et al.
2005/0242675	A1	11/2005	Thornton et al.
2005/0263369	A1	12/2005	Mendenhall
2006/0130699	A1	6/2006	Thornton et al.
2006/0201376	A1	9/2006	Brigham
2007/0044676	A1	3/2007	Clark et al.
2007/0283841	A1	12/2007	Lopatinsky et al.
2008/0006172	A1	1/2008	Thornton
2008/0148990	A1	6/2008	Wamble et al.
2009/0107806	A1	4/2009	Mendenhall
2010/0054897	A1	3/2010	Bufano et al.
2010/0186618	A1	7/2010	King et al.
2010/0192799	A1	8/2010	Miller
2010/0200316	A1	8/2010	Gurol et al.
2010/0236445	A1	9/2010	King et al.
2013/0008336	A1	1/2013	Young et al.
2013/0074724	A1	3/2013	King et al.
2015/0083018	A1	3/2015	Clark et al.

FOREIGN PATENT DOCUMENTS

CN	1194735	A	9/1998
CN	1258029	A	6/2000
CN	1349463	A	5/2002
CN	1451148	A	10/2003
CN	1575538	A	2/2005
CN	1703817	A	11/2005
CN	1906829	A	1/2007
CN	1970410	A	5/2007
CN	100372215	C	2/2008
CN	101356714	A	1/2009
CN	101378931	A	3/2009
CN	101489849	A	7/2009
CN	101574933	A	11/2009
CN	102387973	A	3/2012
CN	101083419	B	3/2013
CN	103717440	A	4/2014
DE	365896	C	12/1922
DE	1 921 714	U	8/1965
DE	1 921 714	A1	2/1970
DE	2 001 330	A1	11/1970
DE	2 024 519	A1	12/1971
DE	2 140 829	A1	2/1973
DE	24 36 466	A1	2/1976
DE	24 45 440	A1	4/1976
DE	25 32 269	A1	2/1977
DE	25 42 805	A1	4/1977
DE	26 13 105	A1	9/1977
DE	26 36 466	A1	2/1978
DE	26 59 010	A1	6/1978
DE	27 10 156	A1	9/1978
DE	27 58 075	A1	7/1979
DE	26 13 105	C3	10/1980
DE	26 59 010	B2	10/1980
DE	26 59 010	C3	11/1983
DE	33 41 787	A1	5/1984
DE	38 33 904	A1	4/1990
DE	41 14 706	C1	10/1992
DE	195 35 856	A1	3/1997
DE	197 17 662	A1	10/1998
DE	298 16 285	U1	1/2000
DE	100 00 513	C1	9/2001
EP	0 093 948	A1	11/1983
EP	0 132 934	A2	2/1985
EP	0 179 188	A2	4/1986
EP	0 229 669	A2	7/1987
EP	0 400 663	A1	12/1990
EP	0 482 424	A1	4/1992
EP	0 593 910	A1	4/1994
EP	0 400 663	B1	8/1994
EP	0 612 446	A1	8/1994
EP	0 455 632	B1	10/1994
EP	0 612 446	B1	9/1995
EP	0 482 424	B1	1/1996
EP	0 695 703	A1	2/1996
EP	0 740 405	A1	10/1996
EP	0 754 366	A1	1/1997
EP	0 816 201	A1	1/1998
EP	0 820 862	A2	1/1998
EP	0 939 482	A2	9/1999
EP	0 939 483	A2	9/1999
EP	0 939 484	A1	9/1999
EP	1 042 152	A4	3/2001
EP	1 232 974	A1	8/2002
EP	1 015 851	B1	11/2002
EP	1 270 311	A2	1/2003
EP	1 270 312	A1	1/2003
EP	1 283 586	A1	2/2003
EP	0 939 299	B1	5/2003
EP	1 418 128	A1	5/2004
EP	0 939 482	B1	2/2005
EP	1 748 943	A4	7/2009
EP	2 131 484	A1	12/2009
EP	2 182 628	A1	5/2010
EP	1 845 428	B1	7/2013
EP	2 747 257	A2	6/2014
FR	433108	A	12/1911
GB	1 170 761	A	11/1969
GB	1 390 375	A	4/1975
GB	1 404 648	A	9/1975
GB	1 418 128	A	12/1975
GB	2 260 743	A	4/1993
JP	54-053412	A	4/1979
JP	56-166763	A	12/1981
JP	57-000068	A	1/1982
JP	59-080190	A	5/1984
JP	59-153457	A	9/1984
JP	60-207666	A	10/1985
JP	62-178104	A	8/1987
JP	62-290385	A	12/1987
JP	01-136504	A	5/1989
JP	01-164205	A	6/1989
JP	03-007003	A	1/1991
JP	03-029747	A	2/1991
JP	03-045105	A	2/1991
JP	03-074109	A	3/1991
JP	03-097380	U	10/1991
JP	04-131198	U	12/1992
JP	05-153764	A	6/1993
JP	05-165521	A	7/1993
JP	05-219786	A	8/1993
JP	05-254660	A	10/1993
JP	06-020766	A	1/1994
JP	06-165313	A	6/1994
JP	06-323803	A	11/1994
JP	07-087618	A	3/1995
JP	07-193914	A	7/1995
JP	07-322596	A	12/1995
JP	08-129336	A	5/1996
JP	08-205514	A	8/1996
JP	08-239121	A	9/1996
JP	09-051688	A	2/1997
JP	09-322518	A	12/1997
JP	11-073600	A	3/1999
JP	11-122902	A	4/1999
JP	11-127505	A	5/1999

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	11-136504	A	5/1999
JP	11-299010	A	10/1999
JP	11-341785	A	12/1999
JP	2001-008312	A	1/2001
JP	2002-058271	A	2/2002
JP	2003-339182	A	11/2003
JP	2004-112864	A	4/2004
JP	4082550	B2	4/2008
JP	4082551	B2	4/2008
JP	4082552	B2	4/2008
JP	4082553	B2	4/2008
JP	4082554	B2	4/2008
JP	4082555	B2	4/2008
JP	4082556	B2	4/2008
JP	4082557	B2	4/2008
JP	4082558	B2	4/2008
JP	4082559	B2	4/2008
KR	2003-0006756	A	1/2003
KR	2003-0013868	A	2/2003
KR	2003-0047877	A	6/2003
KR	2003-0057995	A	7/2003
KR	10-2005-0059230	A	6/2005
KR	10-2007-0011577	A	1/2007
KR	10-2008-0033440	A	4/2008
KR	10-0864990	B1	10/2008
KR	10-0914927	B1	8/2009
KR	10-1004511	B1	12/2010
KR	10-2012-0027110	A	3/2012
KR	10-2014-0038505	A	3/2014
SU	1140212	A1	2/1985
WO	89/05542	A1	6/1989
WO	93/10594	A1	5/1993
WO	94/04404	A1	3/1994
WO	95/17680	A1	6/1995
WO	95/21405	A2	8/1995
WO	96/00958	A1	1/1996
WO	96/27544	A1	9/1996
WO	98/47734	A1	10/1998
WO	98/50760	A2	11/1998
WO	00/64742	A2	11/2000
WO	00/64751	A1	11/2000
WO	00/64753	A1	11/2000
WO	00/64791	A1	11/2000
WO	00/71402	A1	11/2000
WO	00/75603	A1	12/2000
WO	01/85581	A1	11/2001
WO	01/96139	A2	12/2001
WO	03/029651	A2	4/2003
WO	03/052900	A2	6/2003
WO	03/105324	A1	12/2003
WO	2004/018276	A2	3/2004
WO	2005/110898	A2	11/2005
WO	2007/021206	A1	2/2007
WO	2007/108586	A1	9/2007
WO	2009/015249	A2	1/2009
WO	2010/085670	A1	7/2010
WO	2010/098935	A2	9/2010
WO	2010/114656	A1	10/2010
WO	2012/170636	A1	12/2012

OTHER PUBLICATIONS

International Search Report and Written Opinion for Application No. PCT/US2014/056574, mailed Dec. 29, 2014 (17 pages).

International Search Report and Written Opinion for Application No. PCT/US2013/060286 mailed Feb. 18, 2014 (15 Pages).

Japanese Office Action for Application No. 2011-548142 issued Jan. 21, 2014 (11 Pages).

U.S. Appl. No. 11/770,701, filed Jun. 28, 2007, Linear Synchronous Motor Power Control System and Methods.

U.S. Appl. No. 12/259,928, filed Oct. 28, 2008, Three-Dimensional Motion Using Single-Pathway Based Actuators.

U.S. Appl. No. 12/359,022, filed Jan. 23, 2009, Transport System Powered by Short Block Linear Synchronous Motors.

U.S. Appl. No. 12/692,441, filed Jan. 22, 2010, Transport System Powered by Short Block Linear Synchronous Motors and Switching Mechanism.

U.S. Appl. No. 13/490,995, filed Jun. 7, 2012, Versatile Control of a Linear Synchronous Motor Propulsion System.

U.S. Appl. No. 13/623,124, filed Sep. 20, 2012, Transport System Powered by Short Block Linear Synchronous Motors and Switching Mechanism.

Chinese Office Action for Application No. 201280038156.8, issued Jun. 19, 2015 (18 pages).

**Chinese Office Action for Application No. 2010800131883, issued Mar. 7, 2013(7 pages) with partial English summary.

Elliot, Novel Application of a Linear Synchoronous Motor Drive. Cegelec Projects Ltd. IEE. 1997. 5 pages.

International Preliminary Report on Patentability mailed Dec. 27, 2013 for Application No. PCT/US2012/041263 (8 Pages).

**International Search Report & Written Opinion, Application No. PCT/US2010/21839, mailed Mar. 26, 2010. (17 Pages).

**International Search Report and Written Opinion mailed Aug. 6, 2012 for Application No. PCT/US2012/041263 (13 Pages).

Safety of High Speed Magnetic Levitation Transportation Systems. High-Speed Maglev Trains; German Safety Requirements. US Department of Transportation. Office of Research and Development. Jan. 1992, Edition 1, 288 pages. DOT/FRA/ORD-92/01.

Clark, T. M., *Position sensing and control of a linear synchronous motor*. Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology. Thesis towards Doctor of Science Requirements. May 26, 1995, 159 pages.

Gieras, J.F., et al., *Topology and Selection. Linear Synchronous Motors: Transportation and Automation Systems*. CRC Press, Boca Raton, FL, 2000, Chapter 1, pp. 1-42.

Gieras, J.F., et al., *Materials and Construction. Linear Synchronous Motors: Transportation and Automation Systems*. CRC Press, Boca Raton, FL, 2000, Chapter 2, pp. 43-84.

Gieras, J.F., et al., *High Speed Maglev Transport. Linear Synchronous Motors: Transportation and Automation Systems*. CRC Press, Boca Raton, FL, 2000, Chapter 6, pp. 177-215.

Gieras, J.F., et al., *Building and Factory Transportation Systems. Linear Synchronous Motors: Transportation and Automation Systems*. CRC Press, Boca Raton, FL, 2000, Chapter 7, pp. 217-251.

Weisman, R., et al., *Design and Demonstration of a Locally Commutated Linear Synchronous Motor*. SAE Technical Paper Series. SAE International: The Engineering Society. Future Transportation Technology Conference and Exposition, Costa Mesa, CA, Aug. 7-10, 1995, 9 pages.

Encoder Application Handbook. Danaher Industrial Controls, 2003, 16 pages.

Magnetic Levitation Space Propulsion. NASA. Florida Space Institute. University of Central Florida. 2012, 38 pages.

Motors. Power Transmission Design. 1997, pp. A317, and A332-A342.

Ackermann, B., et al., New technique for reducing cogging torque in a class of brushless DC motors. IEE Proceedings B (Electric Power Applications), vol. 139, Issue 4, Jul. 1992, pp. 315-320.

Basak, A., Permanent-Magnet DC Linear Motors. Monographs in Electrical Engineering (Book 40). Clarendo Press, Oxford, 1996, pp. 21-41; 90-104.

Breton, C., et al., Influence of machine symmetry on reduction of cogging torque in permanent-magnet brushless motors. IEEE Transactions on Magnetics, Sep. 2000, vol. 36, Issue 5, pp. 3819-3823.

Duffie, N.A, et al., Distributed system-level control of vehicles in a high-performance material transfer system. IEEE Transactions on Control Systems Technology, vol. 3, No. 2, Jun. 1995, pp. 212-217.

Eghtesadi, M., Inductive power transfer to an electric vehicle-analytical model. 40th IEEE Vehicular Technology Conference, May 6-9, 1990, Orlando, FL, pp. 100-104.

Gieras, J.F., et al., Materials and contruction. Linear Synchronous Motors: Transportation and Automation Systems. CRC Press, Boca Raton, FL, 2000, Chapter 2, pp. 43-84.

Hanselman, D., Ph.D., Brushless Permanent Magnet Motor Design. Second Edition. Magna Physics Publishing, Lebanon, OH, 2006, pp. 209-219.

(56) **References Cited**

OTHER PUBLICATIONS

He, J.L., et al., Survey of Foreign Maglev Systems. Center for Transportation Research, Energy Systems Dvision, Argonne National Laboratory, Argonne, IL, Jul. 1992, 88 pages.
Hendershot, J.R., et al., eds., Design of Brushless Permanent-Magnet Motors (Monographs in Electrical and Electronic Engineering). Oxford University Press, 1995, pp. 3-48-3-67 and 5-28-5-29.
Hor, P.J., et al., Minimization of cogging force in a linear permanent magnet motor. IEEE Transaction on Magnetics, Sep. 1998, vol. 34, issue 5, pp. 3544-3547.
Hughes, A., Synchronous, switched, reluctance and brushless D.C. drives. Ch. 9, 2nd edition. Electric Motors and Drives: Fundamentals, Types and Applications. Butterworth-Heinemann Ltd., 1993, pp. 292-315.
Hugli, S., MagneTrak, Test Specification. Project-No. 133844. Rolex Industries SA. Oct. 18, 2010, 28 pages.
Hwang, S.M., et al., Various design techniques to reduce cogging torque by controlling energy variation in permanent magnet motors. IEEE Transactions on Magnetics, Jul. 2001, vol. 37, issue 4, pp. 2806-2809.
International Search Report for Application No. PCT/US03/30970, mailed Aug. 11, 2004 (3 pages).
International Search Report and Written Opinion for Application No. PCT/US05/15780, mailed Nov. 26, 2007 (10 pages).
Koh, et al., New cogging-torque reduction method for brushless permanent-magnet motors. IEEE Transactions on Magnetics, Nov. 2003, vol. 39, issue 6, pp. 3503-3506.
Li, T., et al., Reduction of cogging torque in permanent magnet motors. IEEE Transactions on Magnetics, Nov. 1988, vol. 24, issue 6, pp. 2901-2903.
Phillips, W.D., Signals. Design Electronics. DOCTRONICS Education Publications, 1998, 12 pages.
Rhoney, B., et al., Principles of AC, DC, Linear, Step, and Servo Motors. MAE 789 C. May 8, 2000, 23 pages. Retrieved from <www.doctronics.co.uk/signals.htm>.
Sands, B.D., The Transrapid Magnetic Levitation System: A Technical and Commercial Assessment. California High Speed Rail Series. University of California Transportation Center, University of California at Berkeley, Mar. 1992, 49 pages.
Strathdee, M., Fledgling Waterloo firm a partner with ATS in parts handling system. Oct. 8, 1998, The Toronto Star Achinve, 2 pages. Retrieved on Oct. 14, 2010 from <http://pqasb.pqarchiver.com/thestar>.
Taniguchi, M., High Speed Rail in Japan: A Review and Evaluation of Magnetic Levitation Trains. California High Speed Rail Series. University of California Transportation Center, University of California at Berkeley, Apr. 1992, 23 pages.
Van Zyl, A.W., et al., Novel secondary design for a linear synchronous motor using a split-pole magnet arrangement. Africon, 1999 IEEE, 1999 vol. 2, pp. 627-630.
Van Zyl, A.W., et al., Reduction of cogging forces in a tubular linear synchronous motor by optimising the secondary design. IEEE Africon 2002, 2002, pp. 689-692.
Zhao, F., et al., Automatic design of a maglev controller in state space. Massachusetts Institute of Technology Artificial Intelligence Laboratory. A.I. Memo No. 1303, Dec. 1991, 20 pages.
Zhu, Z.Q., et al., Reduction of cogging force in slotless linear permanent magnet motors. IEE Proc.-Electr. Power Appl., Jul. 1997, vol. 144, issue 4, pp. 277-282.
Zhu, Z.Q., et al., Novel linear tubular brushless permanent magnet motor. EMD97, IEE, Sep. 1-3, 1997, Conference Publilcation No. 444, pp. 91-95.
Chinese Office Action for Application No. 201410638502.7, issued Mar. 2, 2016 (40 pages).

* cited by examiner

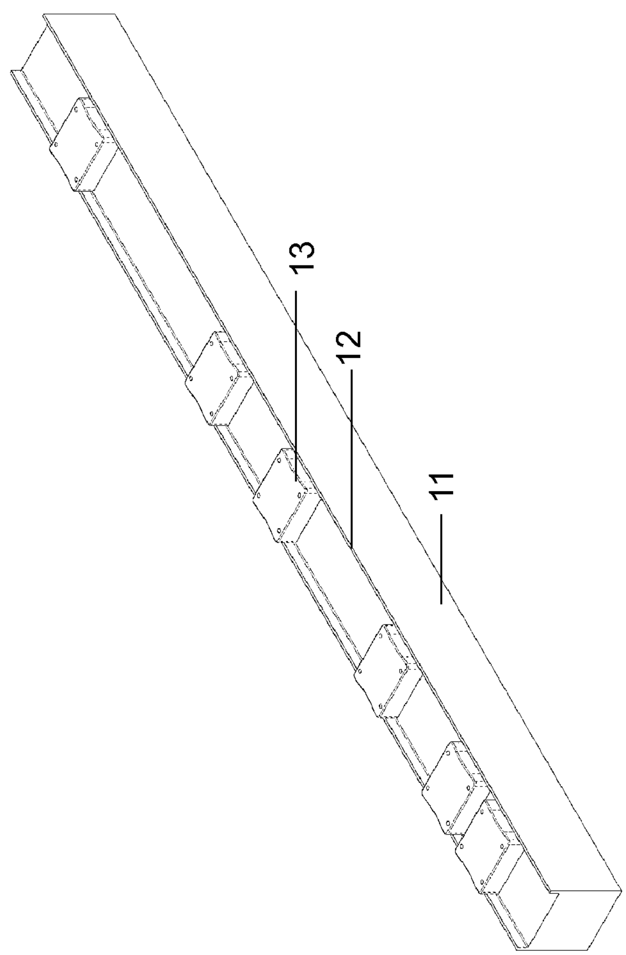


Figure 1. Straight guideway showing vehicles moving in close proximity.

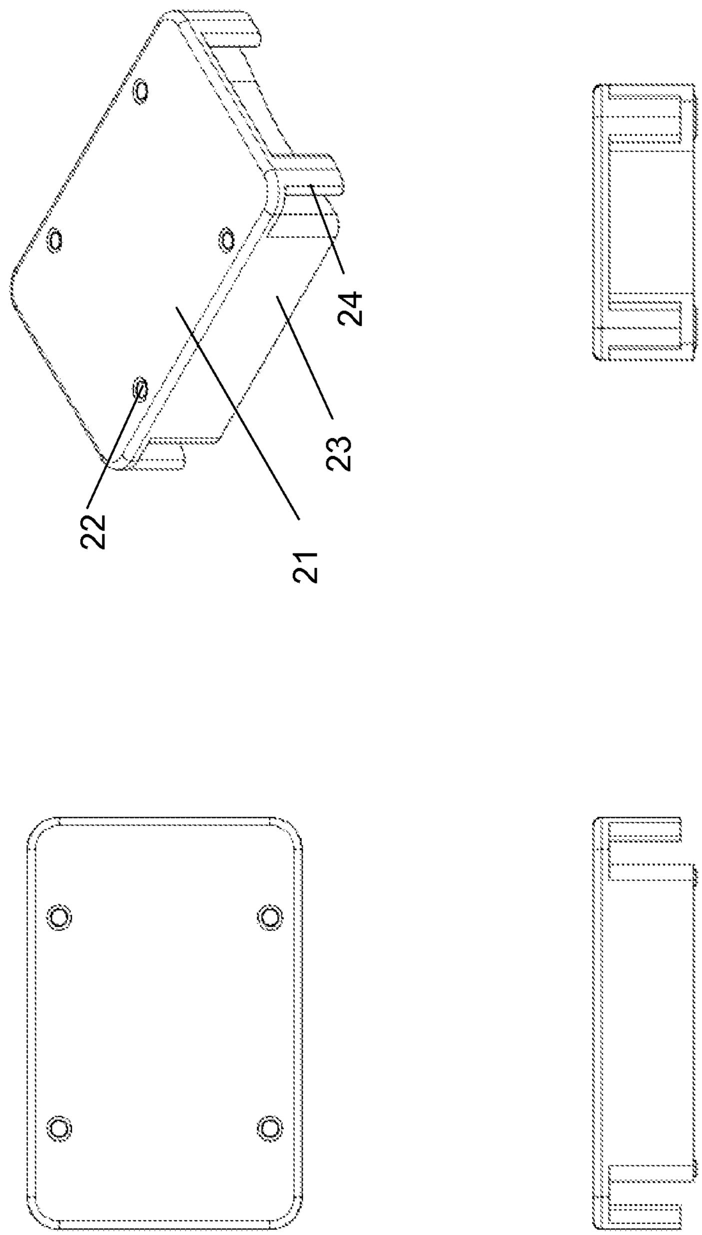


Figure 2. Vehicle for holding objects to be moved.

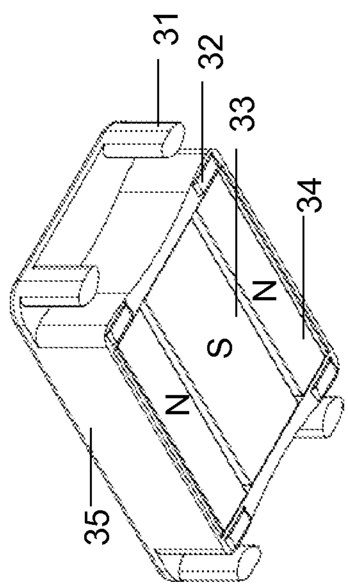


Figure 3. Vehicle showing switch guidance mechanisms and magnet array.

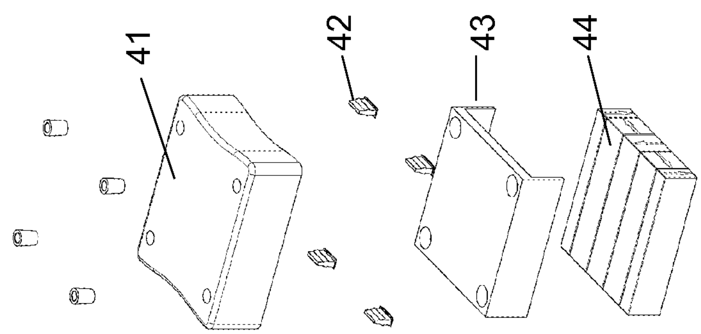


Figure 4. Cutaway view of vehicle showing magnets in a Halbach Array

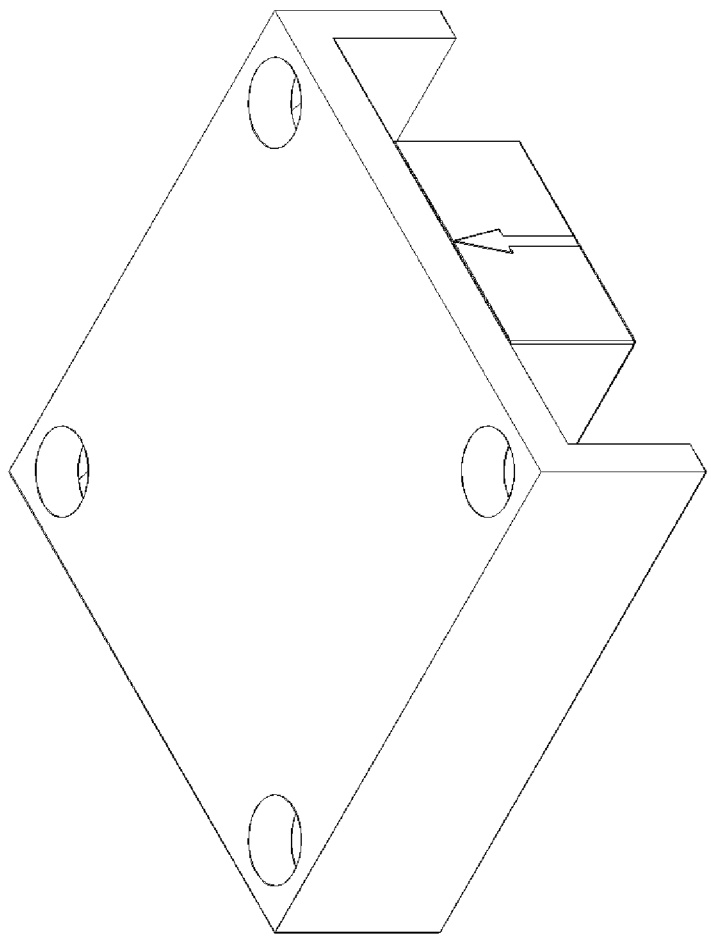


Figure 5. Vehicle with only a single magnet in the magnet array.

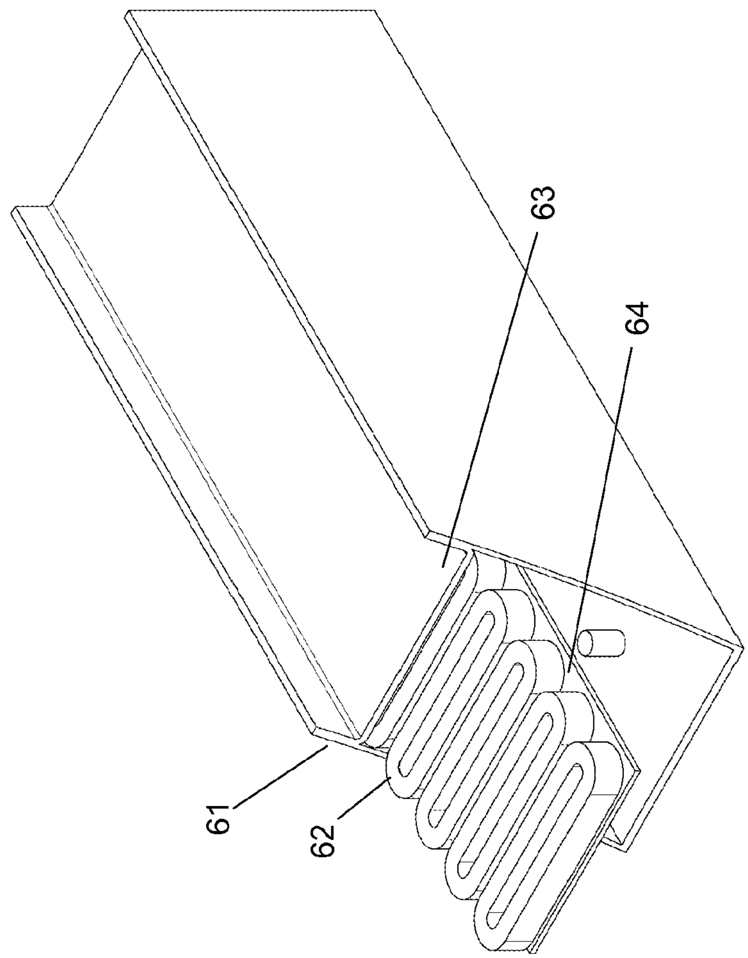


Figure 6. Cutaway housing showing coils mounted close to guideway surface.

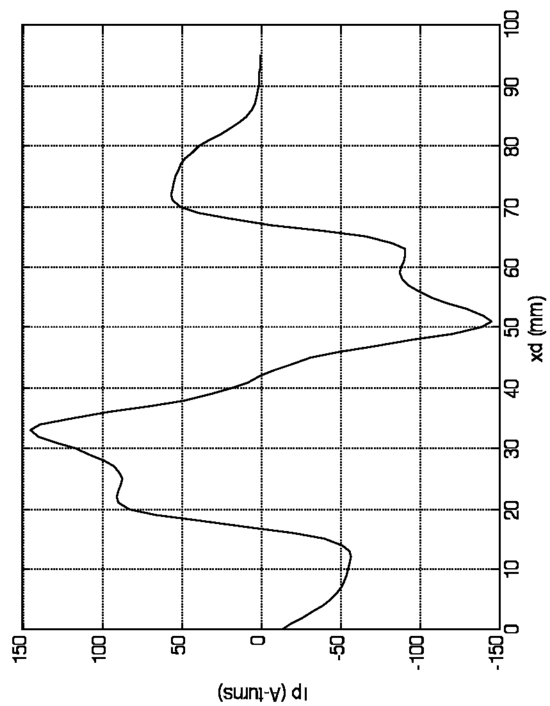


Figure 7. Typical waveform of current in a coil as a vehicle moves by.

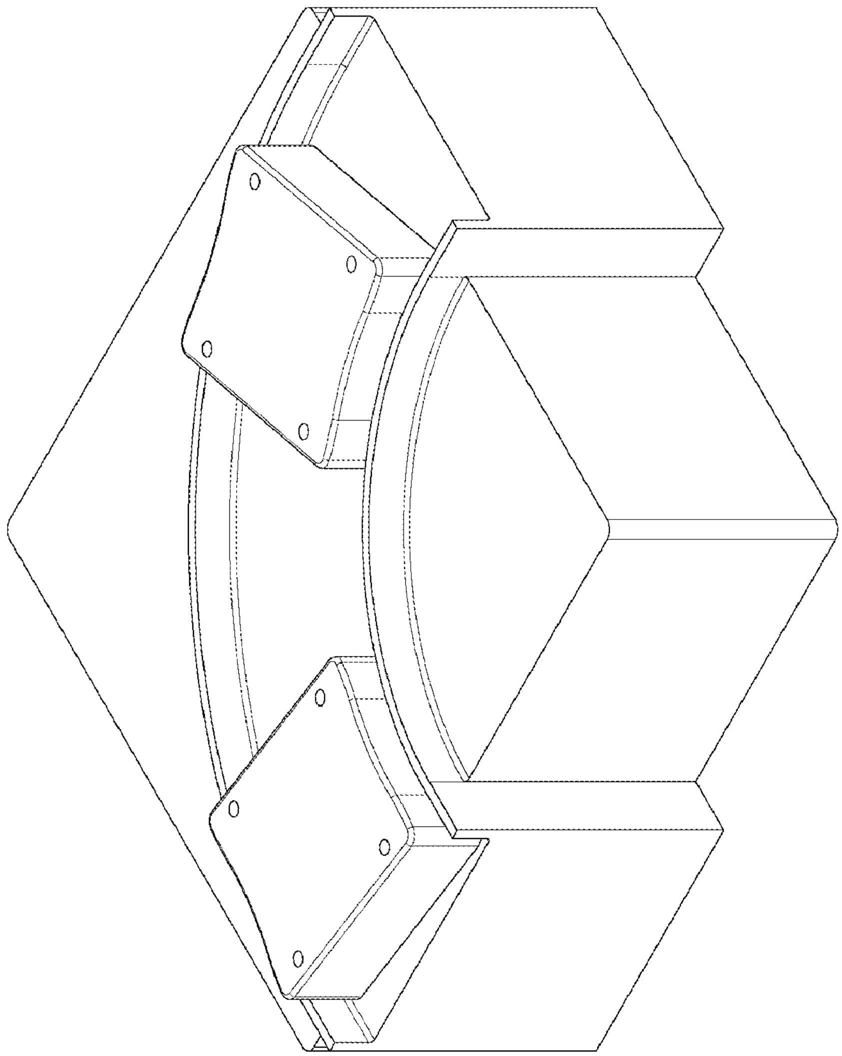


Figure 8. Vehicles negotiating a 90° turn.

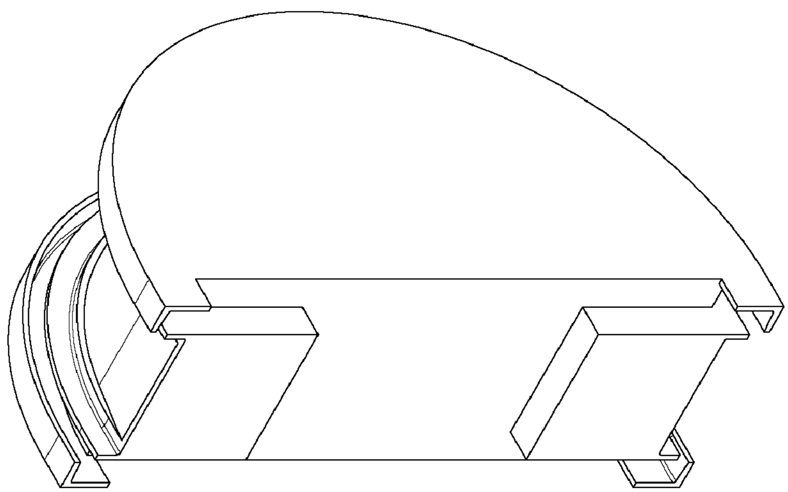


Figure 9. Vehicles negotiating a 180 vertical turn.

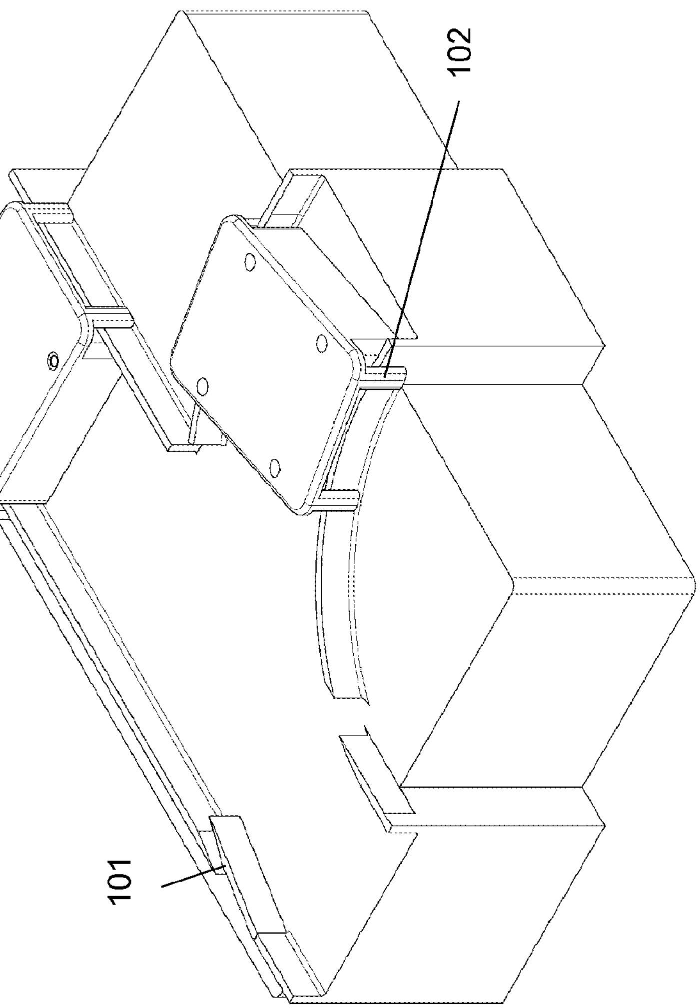
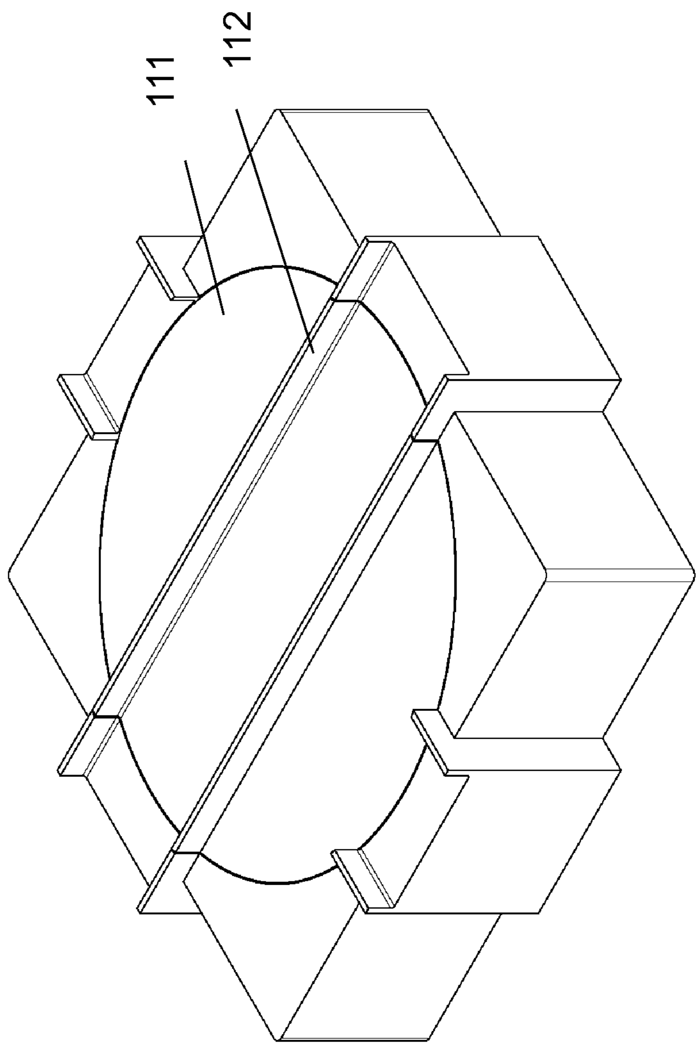


Figure 10. Right diverge showing flippers for controlling direction.

Figure 11. Turntable for turning, merging and diverging.



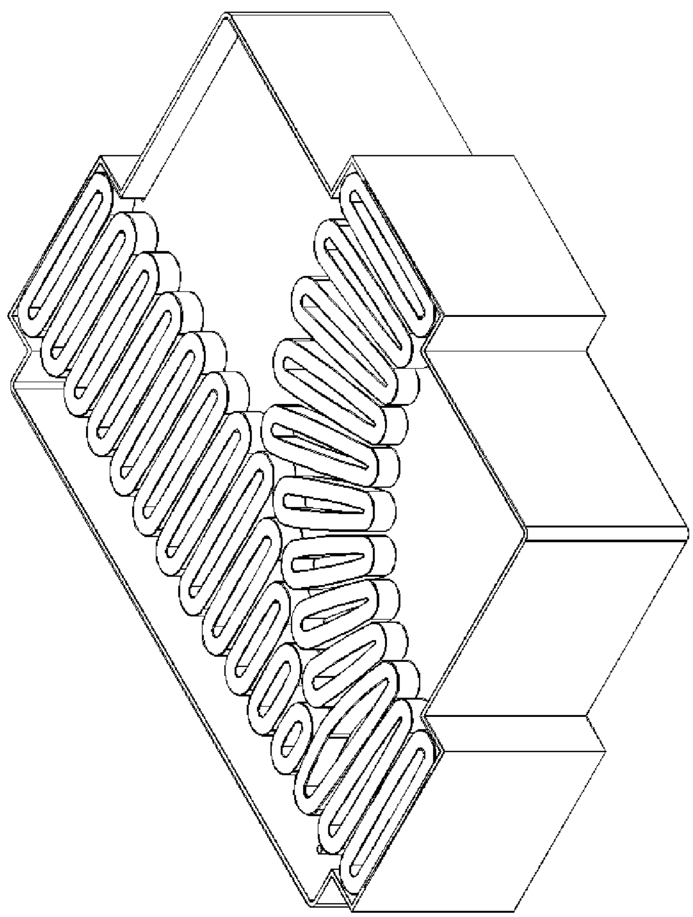


Figure 12. Cutaway view of right diverge showing coils for continuous propulsion

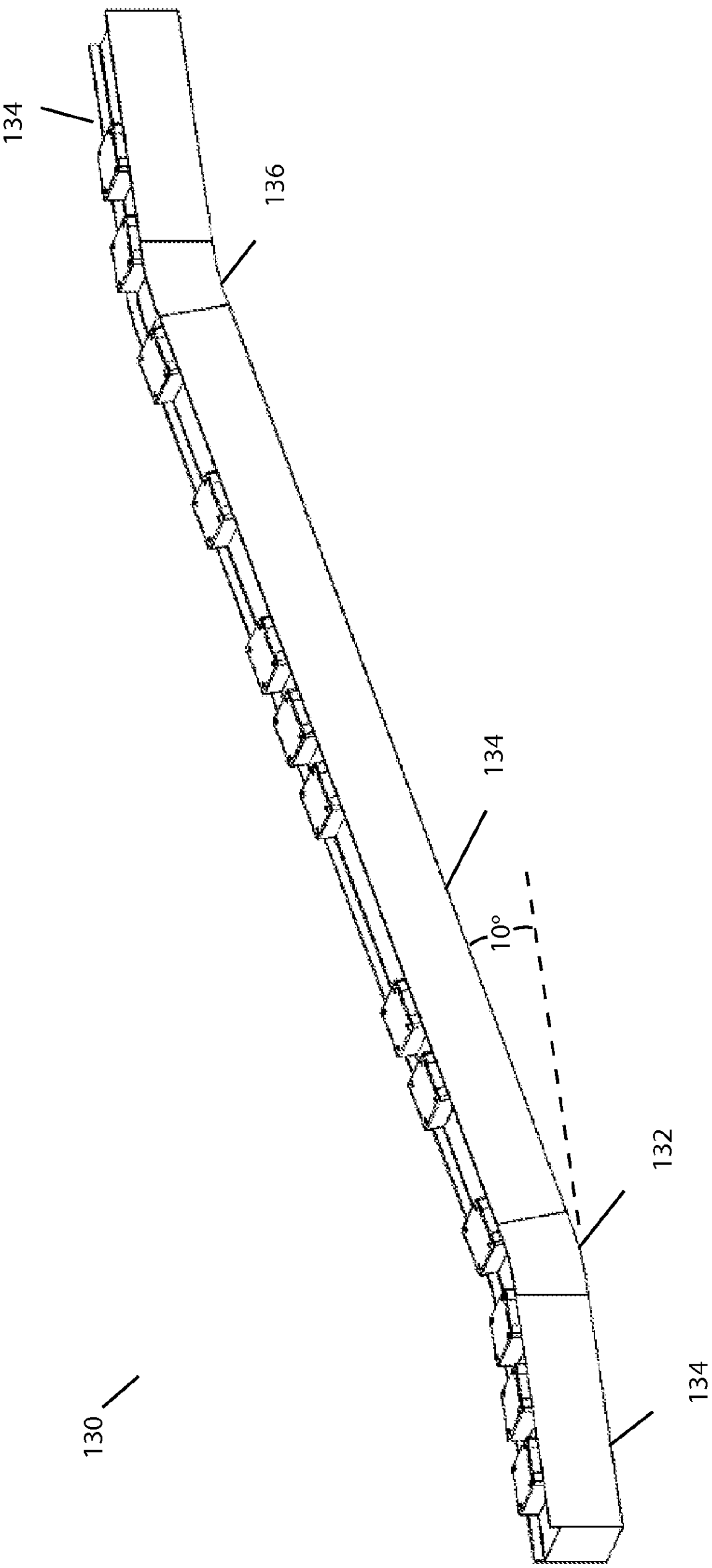


Figure 13. Vertical transition with convex and concave transition pieces

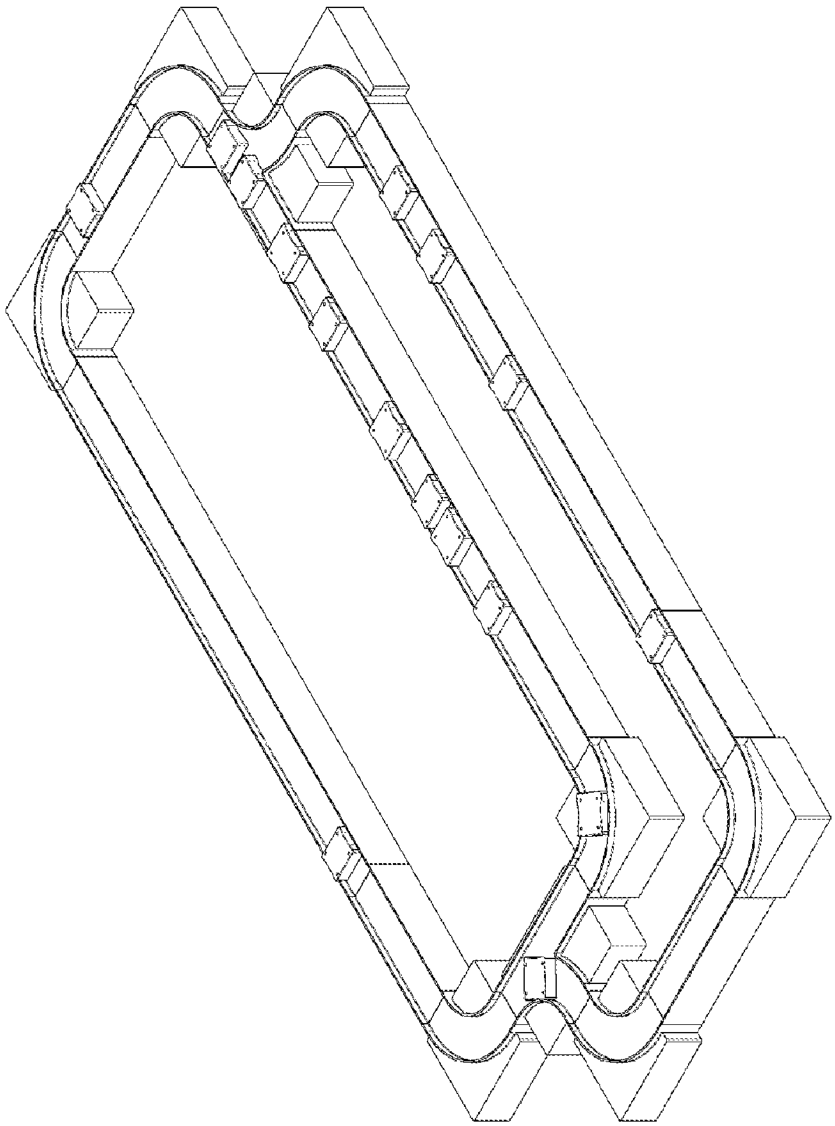


Figure 14. Example of layout showing use of guideway modules.

TRANSPORT SYSTEM POWERED BY SHORT BLOCK LINEAR SYNCHRONOUS MOTORS

This application is a continuation of U.S. patent application Ser. No. 12/359,022, filed Jan. 23, 2009, entitled "TRANSPORT SYSTEM POWERED BY SHORT BLOCK LINEAR SYNCHRONOUS MOTORS," the teachings of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

The invention pertains to transport systems and more particularly, by way of example, to guideway-based transport system with short block linear synchronous motors. The invention has application, by way of non-limiting example, in production lines, laboratories and other applications requiring complex guideways, sharp turns, merge and diverge switching, and/or inverted operation.

There are many types of transport systems that can move objects on a guideway. Examples include: wheel-suspended vehicles propelled by rotary or linear motors, maglev or air-cushion suspended vehicles propelled by linear motors or cables, vehicles that move in tubes propelled by air pressure, vehicles supported or guided by bearings, and vehicles that are moved on conveyor belts. Existing transport systems have many useful applications but there are opportunities for substantial improvement, for example, in the precise movement of relatively small and closely spaced objects on a complex guideway.

Small and medium size objects are often transported on conveyor belts because this eliminates the need for wheels or other mechanisms to suspend, guide and propel the objects. Belt transport systems are relatively inexpensive but they lack precise control that is often needed and they require substantial maintenance because of many moving parts. Other approaches to low cost transport include air propelled vehicle moving in tubes and the use of gravitational forces to move objects down an incline, but these approaches have even less precise control.

The advantages of using linear synchronous motor (LSM) propulsion are well known and described in other patents (by way of non-limiting example, U.S. Pat. Nos. 7,458,454, 7,448,327, 6,983,701, 6,917,136, 6,781,524, 6,578,495, 6,499,701, 6,101,952, and 6,011,508, all assigned to the assignee hereof and the teachings of all of which are incorporated herein by reference), but in many cases, particularly, for example, when moving small and closely spaced objects, the LSM can be more expensive and provide less throughput than competing propulsive systems.

In view of the foregoing, an object of the invention is to provide improved transport systems, apparatus and methods.

A related object of the invention is to provide such systems, apparatus and methods as take advantage of LSM technologies.

Another related object of the invention is to provide such systems, apparatus and methods as are adapted for transport of small objects and/or medium-sized objects.

A further related object of the invention is to provide such systems, apparatus and methods as are adapted for use with closely-spaced objects.

Still another object of the invention is to provide such systems, apparatus and methods as are adapted for use in production lines, laboratories and other applications requiring complex guideways, sharp turns, merge and diverge switching, and/or inverted operation.

SUMMARY OF THE INVENTION

The foregoing are among the objects attained by the invention, which provides in some aspects an LSM-based transport

system that includes a guideway with a plurality of coreless propulsion coils disposed along a region in which one or more vehicles disposed on the guideway are to be propelled, as well as electronic power and control circuitry that excites the propulsion coils independently so as to propel the vehicles along the guideway. The vehicles, according to these aspects of the invention, each include a magnetic flux source—for example, one or more Halbach or other magnet arrays.

Systems according to the foregoing aspect are advantageous for, among other reasons, that the vehicles on the guideway can be moved (or propelled) independently of one another in a controlled fashion—e.g., without risk of collision or uncontrolled motion—regardless of their proximity to other vehicles on the guideway.

Related aspects of the invention provide transport systems as described above in which the vehicles are disposed for sliding motion along guideway. In these aspects, the vehicles can have a low coefficient of friction with the guideway, e.g., a coefficient of friction of less than substantially 0.2.

The guideway, according to related aspects of the invention, can include guidance structure—such as rails—that facilitate maintaining the vehicles on the guideway (or, put another way, that inhibit the vehicles from moving off the guideway).

In related aspects of the invention, the guideway of transport systems of the type described above is made up of a plurality of coupled (e.g., interlocked) modules. The propulsion coils may be mounted in those modules and more particularly, according to some aspects of the invention, on printed circuit boards that make up the modules. The coils are disposed within the modules so as to be in close proximity to magnet arrays (or other flux sources) of vehicles passing over them.

In still other related aspects, the invention provides transport systems as described above in which the modules comprise power controllers that form part of the electronic power and control circuitry and that are selectively electrically coupled to one or more of the propulsion coils, e.g., of the respective modules. Microprocessor(s) and/or switches can also be provided to provide electrical coupling between the power control circuitry and the propulsion coils.

Yet still other aspects of the invention provide transport systems as described above in which the guideway comprises merge and/or diverge regions, each of which may include mechanically and/or magnetically actuated switches to alter the course of passing vehicles. These merge and diverge regions, as well as straight-away regions, that make up the guideway may comprise one or more of the aforementioned coupled modules.

Further related aspects of the invention provide transport systems as described above in which at least one of the diverge regions comprises a plurality of coreless propulsion coils spaced along a region in which the course of passing vehicles is altered—that is, spaced along a corner, curve and/or branch—so as to propel the vehicles through the diverge. According to related aspects of the invention, a merge region can be similarly equipped with a plurality of such coils.

Other aspects of the invention provide guideways, guideway modules and vehicles for use thereon, constructed and/or operated as discussed above.

BRIEF DESCRIPTION OF DRAWINGS

A more complete understanding of the invention may be attained by reference to the drawings, in which:

FIG. **1** depicts a system according to the invention, including a straight guideway and vehicles propelled thereon by an LSM in close proximity while sliding on a low friction guideway surface and guided by rails on the side of the guideway.

FIG. **2** shows details of a vehicle according to one practice of the invention used to hold objects for moving on the guideway in FIG. **1**.

FIG. **3** shows vehicle guidance mechanisms and magnet array in a system according to one practice of the invention.

FIG. **4** is similar to FIG. **3** but with a Halbach Array for the magnets.

FIG. **5** is similar to FIG. **3** but with a single magnet used for propulsion.

FIG. **6** shows a guideway according to one practice of the invention, including a printed circuit board, with propulsion coils mounted on it, in close proximity to the guideway surface, and connected to power control circuitry on the circuit board.

FIG. **7** shows a typical waveform of current in a coil as a vehicle moves by in a system according to one practice of the invention.

FIG. **8** shows vehicles negotiating a sharp 90° horizontal turn in a system according to one practice of the invention.

FIG. **9** shows vehicles negotiating a sharp 180° vertical turn in a system according to one practice of the invention.

FIG. **10** shows a right diverge in a system according to one practice of the invention with vehicle direction determined by the position of a small flipper.

FIG. **11** shows a turntable which can be used in a system according to one practice of the invention in lieu of a curve to effect diverge and merge operations.

FIG. **12** shows propulsion coils providing continuous force on vehicles moving on a right diverge module of a system according to the invention.

FIG. **13** shows a vertical transition in a system according to one practice of the invention.

FIG. **14** shows an example of a system according to the invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

Introduction

Described here is an LSM-based transport system that allows vehicles to move on a guideway that can be complex and that can include sharp horizontal and vertical turns, merge and diverge switching, and inverted operation. Examples of applications include: moving bottles on an assembly line while they are being filled and capped, moving vials in a laboratory for analysis, moving electronic devices along a production line so that robots can insert components, and sorting objects that arrive from a multiplicity of sources and must be delivered to appropriate locations. In some cases it is feasible to use wheels, bearing or other rolling elements to assist in suspension and guidance, but this invention can also be used in cases where there are no wheels (or other rolling elements) and the vehicles slide on a guideway surface. Wheel-less vehicles can be small and inexpensive when the objects to be moved are not too large. For heavier vehicles the same short block design is suitable for wheel- or bearing-based suspension and guidance.

The result is a transport system that provides an economically viable means of using LSM propulsion to propel and control closely spaced small to medium size vehicles on a guideway.

Among other aspects of the systems described herein are LSM motor modules that also function as the transport system track (or "guideway") pieces. A selection of standard track building blocks fit together in a plug-and-play manner to form an almost endless variety of layout options. The motor modules (or "motors", for short) can contain not only the propulsion and intelligent routing elements, but also the guidance and structural support features to allow for rapid assembly and track configuration. The system is ideally suited, by way of non-limiting example, for environments requiring clean operation and/or wash down capability. It can also support "track and trace" requirements, as each vehicle can be uniquely identified and constantly tracked throughout the system.

A suspension system with a coefficient of friction obtainable with sliding motion can beneficially be used with an LSM with negligible attractive force. This is achieved, in the illustrated embodiment, by using a coreless motor with propulsion coils mounted, e.g., in close proximity to the vehicle magnets.

The text that follows describes components and operation of embodiments of the invention. It is understood that many variations on this design are possible and are contemplated by the invention, but this description shows how to achieve the foregoing and other objectives with a simple system that can be manufactured at a reasonable cost.

Guideway

FIG. **1** shows a straight section of guideway with vehicles **13** moving in close proximity. The structure of the guideway can provide guidance in one or more dimensions by rails **12** on the side. For applications where the vehicle does not have wheels they slide on the guideway surface and special materials (discussed below) are used to minimize friction. The guideway housing **11** contains all of the electronics including position sensing means, propulsion coils, power electronic components, and microprocessors.

The design shown in these Figures is based on vehicles that are about 50 mm wide and 50 to 60 mm long. For larger objects the guideway and vehicle dimensions can be scaled, much as model railroads have been constructed with a variety of scaling factors.

Vehicle

FIGS. **2** and **3** show a vehicle **21** that can be used as part of the proposed transport system. It is relatively small, about 50 mm square and 20 mm high, and has components **32** on the lower surface that slide on the guideway running surface. Holes **22** in the top of the vehicle are used to mount support mechanisms for the objects that are to be moved.

The vehicle has curved sides **23** that match the sides of a curved guideway so as to allow short radius horizontal turns. It is guided by the guideway and can move in a normal upright position when transporting an object as well as moving in an inverted position when not carrying an object. It can also negotiate vertical turns. Pins **24**, **31** in the corners of the vehicle interact with mechanisms in the diverge and modules so as to control the direction of motion.

FIG. **3** is a view of the lower surface of the vehicle and shows the permanent magnets **33**, **34** that are mounted near the bottom of the vehicle and provide the means for LSM propulsion.

FIG. **4** shows a variation of FIG. **3** in which a Halbach Array **44** is used for the magnet structure so as to create higher force for a given weight. FIG. **5** shows a single magnet structure **51** that is suitable for applications where less force is required.

Larger objects can be moved on this same guideway by using a double-bogey design, as has been used with conventional LSM designs (see, for example, U.S. Pat. No. 7,458,454, entitled "Three-dimensional Motion Using Single-Pathway Based Actuators," issued Dec. 2, 2008, and U.S. Patent Application 2007/0044676, entitled "Guideway Activated Magnetic Switching of Vehicles," published Mar. 1, 2007, the teachings of both of which are incorporated herein by reference), or by increasing the dimensions of guideway and vehicles.

Low Friction Sliding Surface

In order to reduce the required propulsive force and heating from friction, the vehicle and guideway of the illustrated embodiment are designed to minimize the coefficient of friction c_f, which is the ratio of the propulsive force needed to move the vehicle to the gravitational force of the vehicle on the guideway. In some cases wheels can be used as a way to reduce this force, but this invention allows the use of wheel-less vehicles. FIG. **6** shows the guideway with low friction surface **63** that supports vehicles in close proximity to the propulsion coils **64**.

Examples of low friction for wheel-less applications include Teflon sliding on Teflon and Teflon sliding on stainless steel. Lower friction is possible if the surface can be lubricated by a thin film, but for many applications this is not allowable so the design assumes no lubrication. It is also preferable that the surface have good wear characteristics so, for example, we might use stainless steel on the guideway and Teflon on the vehicle with the expectation that there would be negligible wear on the steel but the vehicle might eventually need to have its sliding surface replaced, an action that is less expensive than replacing the guideway. Sliders **32** in FIG. **3** are examples of how low friction components can me mounted. They may be designed so as to be replaceable if it is expected that they will wear out before the vehicle reaches end of life.

With some designs c_f can be as low a 0.1 but more practical values are in the range 0.15 to 0.2. Because this is a relatively high value it is preferred that the propulsive force not create substantial downward force on the vehicle. A typical LSM using ferromagnetic material will exert an attractive force that is four to six times the propulsive force and with this much attractive force the vehicle may not be able to move, or if it did move there would be substantial heating and power wasted—in such instances, wheels, bearings or other rolling elements can be incorporated for suspension of the vehicles.

Magnet Array

There are many types of magnet arrays that can be used, one of which is shown in FIG. **3**. With this design there is one middle magnet **33** that has the South pole on the lower surface and two half magnets **34** on the ends that have a North Pole on the lower surface. Typically the magnets use NdFeB in order achieve high fields but they can use other materials, such as ceramic when cost or external fields must be low or Samarium Cobalt when the operating temperature is high.

One design consideration is the interaction between magnets on adjacent vehicles. The ferromagnetic piece **35** largely prevents magnetic fields from adjacent vehicles from interfering with each other.

FIG. **4** shows a Halbach Array which can be used where higher force is required and the added cost is acceptable. With this design the magnetic field rotates from one magnet to the next with a resulting higher propulsive force than is possible with the magnet design in FIG. **3**. Ferromagnetic shield **43** minimizes interactions between the fields of adjacent vehicles.

FIG. **5** shows a single magnet providing all of the magnetic flux with ferromagnetic material on the ends used to provide a return path. This may not produce as much force but can be less expensive than multi-magnet designs.

Linear Motor Propulsion

FIG. **6** shows coils **64** mounted in close proximity to the guideway running surface **63**. Currents in these coils are individually controlled via power electronic components and microprocessors so that each vehicle can be individually controlled even when it is touching neighboring vehicles.

A feature of the illustrated embodiment is the lack of ferromagnetic material that is commonly used in an LSM to make it more efficient. With no ferromagnetic material we can not achieve as high a force, but we can limit the attractive force to a small fraction of the propulsive force and thereby allow strong acceleration and braking forces to move the vehicle when the coefficient of friction is on the order of 0.2 or higher.

In embodiments that use wheel-based vehicles the friction force may be small enough that some ferromagnetic material can be used in the stator so as to achieve higher propulsive force.

Software for controlling the microprocessors can be similar to control software used on LSM designs with blocks that are several coils long. Here, however, position sensing components are located close enough together that they can identify individual vehicles even when the vehicles are touching. Such sensing facilitates control of the movement of the vehicles independently of one another on the guideway. Prior demonstrations of locally commutated LSMs have shown that this software does not require special features.

PC Board Mounted Coils and Control Circuitry

The illustrated embodiment permits the control of each coil individually without the cost associated with conventional designs. With reference to FIG. **6**, there is shown an embodiment in which the coils **62** are mounted directly on a Printed Circuit Board (PCB) **64**. This board supports the coils and provides connections between the coils and the power electronic modules that control the current. Typically each coil is connected to the output of an "H-bridge" with MOSFET or IGBT devices used to control the amount and direction of current in each coil. These components are mounted on the same PCB. The PCB also holds Hall Effect devices that sense the magnetic field produced by the vehicle and allow a microprocessor to create a desired force. FIG. **7** shows a typical waveform of the current in a propulsion coil that will propel a vehicle as it moves by the coil. By proper choice of waveform several propulsion coils can work in unison to create a constant force on the vehicle with minimum power loss in the coil. For braking the sign of the current is reversed.

By mounting the coils directly on a PC board and by using integrated power controllers it is possible to reduce the cost for the coils and electronics. One microprocessor can control a multiplicity of H-bridges but with a coil spacing on the order of 16 mm there can be more than a dozen microprocessors per meter of motor, and the operation of these motor controllers must be coordinated by a higher level "node" controller. With modern semiconductor technology, and for low to moderate power levels, all of these components can be mounted on only one or two PCBs that are contained in the motor housing.

Guideway Modules

The guideway is built of modules much as a model train layout is constructed from modules. FIGS. **6**, **8**-**11** and **13** show examples of a straight section, a 90° horizontal curve, a

180° vertical curve, a right diverge switch, a turntable, and a vertical transition. These components can be interconnected in a variety of ways to meet the requirements of many and diverse applications.

The 180° vertical curve in FIG. **9** is primarily used as a means to return empty vehicles to a starting point and vehicles negotiating this curve may be controlled and propelled by other means than an LSM. For example, vehicles going down may be propelled by gravity and vehicles going up may be propelled by interaction with a mechanical mechanisms and in both cases there may not be precise control during the curve transition. It is preferable that once the vehicles have negotiated this curve precise control is regained. In some cases there is a vertical curve with a much larger curve radius, such as used as a transition between a level guideway and an inclined guideway. (See, for example, FIG. **13**). In this case LSM propulsion can be used for the vertical curve and thereby retain precise control through the curve.

FIG. **9** shows a right diverge using a small mechanical or magnetic flipper **101** that directs a moving vehicle to go either straight ahead or diverge to the right. The flipper is controlled by a linear or rotary actuator that interacts with pins **102** on the vehicle to steer the vehicle in the correct direction. The same device can be used to merge two streams of vehicles. The flipper is small and light so it can move from one position to another in a small fraction of a second and thereby allow high throughput with adjacent vehicles able to be switched independently. A left diverge can be constructed as a mirror image of the right diverge.

FIG. **11** shows a turntable **111** as an alternative to the flipper. Guidance rails **112** on the turntable and propulsion coils, not shown, guide and propel the vehicle. The turntable in FIG. **11** can rotate in 90° increments, but other designs can support motion for a variety of angles. The turntable tends to be slower than the flipper because of the added mass, but is less expensive for some applications and has greater versatility because it can be used in lieu of curves as well as to reverse vehicle direction and switch between a multiplicity of tracks.

FIG. **13** depicts a vertical transition **130**. In the illustrated embodiment, this includes a concave transition piece **132**, straight sections **134** and a convex transition piece **136**, coupled as shown. The illustrated transition is 10° along the vertical axis, though, in other embodiments greater or lesser angles may be employed. Although the angle of the vertical transition shown here is established by transition pieces **132**, **136**, in other embodiments the transition may be defined by other pieces (e.g., incorporated into diverges, straight-sections, and so forth).

The switching function can also be provided by magnetic forces acting on the vehicle. For example, coils on and near the guideway can be controlled so as to create lateral forces that will perform the switching function. This approach to switching is described in U.S. Patent Application US 2007/0044676, entitled "Guideway Activated Magnetic Switching of Vehicles," the teachings of which are incorporated herein by reference.

FIG. **12** shows a cutaway view of a guideway diverge module showing propulsion coils for propelling vehicles on either of two paths. This continuous propulsion through a diverge or merge is essential to providing precise position control at all times.

A further appreciation of techniques for packaging the linear motor and other module components of the guideway modules may be attained by reference to U.S. Pat. No. 6,578,495, entitled "Modular Linear Motor Tracks and Methods of Fabricating Same," assigned to the assignee hereof, the teachings of which are incorporated herein by reference.

Application Example

There are many possible applications but the simple layout in FIG. **14** shows how the guideway modules can be interconnected. Vehicles move around the main loop but can move though a bypass when desired. Typical applications will use many more guideway modules than in this simple example.

Described above are systems, apparatus and method meeting the foregoing objects, among others. It will be appreciated that the embodiments illustrated and discussed herein are merely examples of the invention and that other embodiments, incorporating changes thereto, fall within the scope of the invention. Thus, by way of non-limiting example, the invention can be practiced with embodiment in which suspension is provided by air-cushion and fluid-cushion, e.g., in addition to the wheel-less, wheeled, and other roller-based designs discussed above, of which we claim:

The invention claimed is:

1. A transport system, comprising

A. a guideway including a plurality of propulsion coils disposed along a region in which vehicles are to be propelled,

B. plural vehicles disposed on the guideway, each containing a magnetic flux source,

C. electronic power and control circuitry that excites the propulsion coils so as to propel the plural vehicles independently of one another along the guideway,

D. one or more sensors that monitor positions of the vehicles moving on the guideway, and

E. wherein any of

(i) one or more of the vehicles are slidingly disposed on the guideway, and/or

(ii) the propulsion coils are mounted on one or more printed circuit boards.

2. The transport system of claim **1**, further comprising a guidance structure on any of the guideway and one or more of the vehicles that inhibit the one or more vehicles from moving off the guideway.

3. The transport system of claim **2**, wherein the guidance structure comprises one or more rails that are disposed on the guideway.

4. The transport system of claim **1**, wherein the magnet flux source of at least one of the vehicles comprises one or more magnets.

5. The transport system of claim **4**, wherein the plurality of coils are disposed in the guideway for close proximity to the one or more magnets of passing vehicles.

6. The transport system of claim **4**, wherein the one or more magnets comprise a Halbach magnet array.

7. The transport system of claim **1**, wherein the guideway comprises a plurality of coupled modules.

8. The transport system of claim **7**, wherein one or more of the modules include one or more of the printed circuit boards with propulsion coils mounted thereon.

9. The transport system of claim **8**, wherein one or more of the modules comprise one or more power controllers that form part of the electronic power and control circuitry and that are selectively electrically coupled to one or more of the propulsion coils.

10. The transport system of claim **9**, wherein the one or more power controllers are selectively electrically coupled to the propulsion coils of the associated module for independent control thereof.

11. The transport system of claim **10**, wherein one or more of the modules comprise one or more microprocessors and one or more switches that provide electrical coupling between the power control circuitry and the propulsion coils.

12. The transport system of claim **1**, wherein the one or more sensors are located close enough together that they can identify individual vehicles.

13. The transport system of claim **12**, wherein the one or more sensors are located close enough together that they can identify individual vehicles even when the vehicles are closely spaced.

14. The transport system of claim **1**, wherein one or more of the propulsion coils are coreless.

15. The transport system of claim **1**, wherein the guideway includes at least one of a merge region and a diverge region.

16. The transport system of claim **15**, wherein the guideway comprises a straight-away region, along with at the least one of a merge region and a diverge region.

17. The transports system of claim **16**, wherein any of the merge region and the diverge region include a mechanically actuated switch that alters a course of a vehicle passing thereon.

18. The transport system of claim **16**, wherein any of the merge region and the diverge region include a magnetically actuated switch that alters a course of a vehicle passing thereon.

19. The transport system of claim **15**, wherein one or more of the vehicles that are slidably disposed on the guideway have a coefficient of friction with the guideway of less than about 0.2.

20. The transport system of claim **15**, wherein at least one of said merge regions and diverge regions includes a plurality of coreless propulsion coils disposed along a region in which the course of passing vehicles is altered.

21. The transport system of claim **15**, wherein at least one of said merge regions and diverge regions includes a plurality of coreless propulsion coils disposed along a corner, curve and/or branch defining the merge or diverge, respectively, so as to propel the vehicles therethrough.

22. A transport system comprising
- a guideway comprising one or more rails that guide a vehicle;
- a plurality of vehicles, each that interacts with the guideway rails for guidance and each containing one or more magnet arrays that can be used for propulsion;
- a multiplicity of coils that are mounted in close proximity to the magnets of passing vehicles and can be excited independently so as to provide forces on the vehicle magnets so as to propel the vehicles independently of one another;
- functionality that interconnects the coils to electronic power control circuitry and that includes switching devices and one or more microprocessors;
- one or more position sensors that monitor the position of vehicles moving on the guideway;
- microprocessors that control the coil currents in response to commands and synchronized to the motion of the vehicles;
- an energy source that provides power for the propulsion of the vehicles; and
- wherein any of
  - (i) one or more of the vehicles are slidingly disposed on the guideway and
  - (ii) the propulsion coils are mounted on one or more printed circuit boards.

23. The transport system of claim **22**, wherein a surface on the lower side of each of the plurality of vehicles slides with a coefficient of friction of less than about 0.2 on a surface on the guideway.

24. The transport system of claim **22**, wherein at least one of the plurality of vehicles is approximately 50 mm square.

25. A guideway module for use in a transport system, the guideway module comprising
- A. one or more coreless propulsion coils disposed along a region in which plural vehicles that include magnetic flux sources are to be propelled,
- B. electronic power and control circuitry that excites the one or more propulsion coils independently of one or more other propulsion coils in any of
  - (a) the guideway module, and
  - (b) a guideway in which that guideway module is incorporated, so as to control movement of the plural vehicles passing over the guideway module independently of one another,
- C. one or more position sensors that monitor the position of vehicles moving on the guideway, and
- D. the propulsion coils are mounted on one or more printed circuit boards.

26. The guideway module of claim **25** adapted for sliding motion of one or more vehicles thereon.

27. The guideway module of claim **25**, further comprising a guidance structure that inhibits motion of vehicles off the guideway.

28. The guideway module of claim **25** adapted for interlocking coupling with one or more such modules.

29. The guideway module of claim **25**, comprising one or more power controllers that form part of the electronic power and control circuitry and that are selectively electrically coupled to one or more of the propulsion coils.

30. The guideway module of claim **25**, wherein the guideway module defines any of a merge and a diverge that alters a course of a vehicle passing thereon.

* * * * *